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ARR Dec. 1942

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

December 1942 as
Advance Restricted Report

THE EFFECT OF VARIOUS SURFACE CONDITIONS ON PRESS FITS OF STEEL BUSHINGS AND 17S-T ALUMINUM-ALLOY FITTINGS

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WASHINGTON

W-35

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ADVANCE RESTRICTED REPORT

THE EFFECT OF VARIOUS SURFACE CONDITIONS ON PRESS FITS OF STEEL BUSHINGS AND 17S-T ALUMINUM-ALLOY FITTINGS

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SUMMARY

Specimens of 17S-T aluminum-alloy fittings with pressed-in steel bushings were tested for various surface conditions. The maximum load required to insert the bushing into the fitting was measured when both surfaces were bare, when the 17S-T was anodically coated and the steel cadmium-plated, and when either surface was treated and the other bare, both without lubrication and with Gredag No. 83 as a lubricant. Coefficients of friction for the various press fits were determined from these loads and from the calculated pressures on the specimens. Use of anodic coating on the aluminum-alloy fitting reduced the load required for a press fit to less than one-half and use of cadmium plating on the steel bushing, to less than one-third the load required when both surfaces were bare. The use of the lubricant was very beneficial when both surfaces were bare but had little effect for the other surface conditions.

INTRODUCTION

In aircraft construction it is common practice to use aluminum-alloy fittings with pressed-in steel bushings to make connections between certain structural members and for parts of the control system. Such fittings have been under discussion recently because of the possibility that the stresses set up by pressing in the bushing might promote stress-corrosion cracking in the fitting. It has been concluded, however, that if the interference between the bushing and fitting is properly controlled, the stresses set up by a press fit can be kept within safe limits. (Interference is here used to mean the difference between the outside diameter of the bushing and the inside diameter of the fitting before the press fit is made.)

It is recognized that, in order to accomplish the desired control of stresses produced by press fits, it is necessary to avoid galling between the bushing and fitting as the bushing is being pressed into the fitting. If such galling occurs, the effective interference between the bushing and fitting is doubtless increased; and as a result the stresses will be higher than intended. Because of the importance of avoiding galling, it was decided to compare the galling tendencies of press fits made with various surface conditions as outlined herein.

TEST SPECIMENS

The aluminum-alloy samples for this investigation were not actual aircraft fittings but were simply disks cut from 2- by 3/4-inch-17S-T rolled bar. Each disk was $1\frac{5}{8}$ inch in diameter and 3/4 inch thick. The disks were pierced at the center with a round hole carefully bored to give the required interference for the 7/8-inch-diameter steel bushings, which were later pressed into the disks. Figure 1 shows the finish on the inside surface of one of these disks.

The steel bushings were made from 7/8-inch-diameter drill rod. Each bushing had a nominal inside diameter of 5/8 inch and a nominal outside diameter of 7/8 inch. The length of each bushing was 13/16 inch, with a slightly rounded leading edge to facilitate entrance of the bushing into the fitting. The steel drill rod was selected for roundness and size and, as a result, no machining was required on the outside surface.

Eight disks and eight bushings were prepared. One-half of the bushings were cadmium-plated by the Finishes Division at the New Kensington Works. The outside diameter of all bushings was determined to the nearest 0.0001 inch by a Zeiss optimeter in conjunction with Hoke precision gage blocks. The holes in the 17S-T disks were bored to give an inside diameter nominally 0.0025 inch less than the outside diameter of the steel bushings. One-half of the 17S-T disks were anodically coated by the Finishes Division at the New Kensington Works using the chromic acid process, the coating being applied after the holes had been bored to size.

When all the disks had been prepared, including the anodic coating, their inside diameters were carefully determined by use of Hoke precision gage blocks. Table I gives the measurements of the inside diameters of these disks as well as the measurements of the outside diameters of the steel bushings and the corresponding interferences. It will be noted that the interferences vary from 0.0021 to 0.0028 inch.

It was recognized throughout this investigation that, since metals with different coefficients of expansion were being used, the interference would change with variations in temperature. It is estimated that the total change in temperature of the parts during this investigation did not exceed 10° F. Such a change in temperature would not appreciably affect the interference.

The nominal interference of 0.0025 inch, which was selected for this investigation, is approximately equal to the maximum interference recommended on this size of bushing by some aircraft manufacturers. All the actual interferences proved to be within 16 percent of the intended nominal value.

The general proportions of the specimens used in this investigation, especially the wall thicknesses of the steel bushings and 17S-T fittings, are believed to be in accordance with current aircraft practice.

TEST PROCEDURE

The bushings and fittings were prepared for press fits by cleaning all faying surfaces with acetone. Following this treatment, some of the surfaces were coated with Grodag No. 83 as a lubricant. The press fits were then made with a 20,000-pound capacity Amsler testing machine. Table I shows the conditions of the surfaces of each fitting and bushing and the loads required to insert the bushing. In all cases the bushings were pushed through the fittings so that the loading edge of the bushing projected approximately 1/16 inch from the side of the fitting opposite to which it entered. In all cases the autographic load-deformation diagrams indicated that the pressure increased gradually as the bushing entered the fitting and finally reached a maximum value when the press fit was nearly complete. It is this maximum load which is recorded in table I.

The calculated pressures and stresses in the specimens produced by the press fits are shown in table II. These pressures and stresses were calculated from the following formulas developed by Mr. H. N. Hill, based on a general method of analysis presented by S. Timoshenko in reference 1:

Radial pressure between bushing and disk:

$$p = \frac{D}{b}\left[\frac{1}{\frac{1}{E_s}\left(\frac{a^2 + b^2}{b^2 - a^2} - \mu_s\right) + \frac{1}{E_A}\left(\frac{b^2 + c^2}{c^2 - b^2} + \mu_A\right)}\right]$$

Stresses in bushing:

$$S_t = -p\,\frac{2b^2}{b^2 - a^2}$$

$$\tau_{max} = p\,\frac{b^2}{b^2 - a^2}$$

Stresses in disk:

$$S_t = p\,\frac{c^2 + b^2}{c^2 - b^2}$$

$$\tau_{max} = p\,\frac{c^2}{c^2 - b^2}$$

where

a inside diameter of bushing, inches

b average outside diameter of bushing and inside diameter of ring, inches

D interference, inches

c outside diameter of ring, inches

p radial pressure between bushing and ring, pounds per square inch

E_s Young's modulus for steel (29,000,000 lb/sq in.)

E_A Young's modulus for aluminum alloy (10,500,000 lb/sq in.)

μ_s Poisson's ratio for steel (0.25)

μ_A Poisson's ratio for aluminum alloy (0.33)

S_t tangential stress, pounds per square inch

τ_{max} maximum shear stress, pounds per square inch

The preceding equations are applicable only within the elastic range and for the idealized case in which a cylindrical steel bushing of uniform wall thickness is pressed into a central circular hole in an aluminum-alloy disk of uniform depth equal to the length of the bushing. Because these conditions are not exactly met in these specimens, the calculated values are only approximately correct.

After the eight press fits had been completed, the specimens were sawed in half across the diameter in order to release the bushing and expose the faying surfaces of the disks and bushings. One-half of each disk and bushing, properly identified, was then submitted to the Metallurgical Division for examination.

DISCUSSION OF RESULTS

Table I indicates clearly that the maximum load required for a press fit in this investigation occurred in the case of specimen 1, in which both the steel and the aluminum-alloy surfaces were bare and no lubricant was applied. This load is from $2\frac{1}{2}$ to $4\frac{1}{2}$ times as great as those required for the other press fits. It should be noted, however, that specimen 1 had the greatest interference between bushing and fitting. The difference in interference between the various specimens impairs the value of any direct comparison of the loads required for the press fits.

In order to overcome the difficulty presented by the variation in interference in the various specimens in this investigation, the diagram shown in figure 2 was prepared. The basis of this diagram is a curve prepared from data from a similar investigation which involved press fits made with steel bushings in 14S-T disks by use of a contact of bare steel to aluminum alloy, lubricated with Gredag No. 83. These bushings and disks were the same size as those used in this investigation except for a slightly thicker wall on the bushings. Plotted with this general curve in figure 2 are the results of the eight press-fit tests taken from table I. In order to adjust the loads required for these eight various press fits so that each would represent the same value of interference, a curve was drawn through each data point and the origin, this curve in each case being of the same general shape as the master curve taken from the other investigation. Each of these curves is shown in figure 2 from the data point up to the vertical line representing an interference of 0.0028 inch. The intersection of these various curves with this vertical line gives the load that would have been expected if the interference had been 0.0028 inch for each press fit. Because this common value of interference 0.0028 inch was used, no adjustment was required for the load on specimen 1. The adjusted loads for an interference of 0.0028 inch are shown in the last column of table I and will be used in all the following comparisons.

In making comparisons of the various loads required for the press fits, it is recognized that small differences in these loads are probably not significant. It can be seen in figure 2 from the data from the other investigation that the scatter in duplicate tests in the range of interferences under consideration may easily be as much as 400 pounds. It will be assumed, therefore, throughout this discussion that differences less than 400 pounds are probably of no significance.

It is clear from a comparison of specimens 1 and 5 that the use of Grodag No. 83 as a lubricant on otherwise bare steel and 17S-T surfaces reduced the load required for a press fit to about one-half the load required for an unlubricated contact of bare steel to aluminum alloy. A comparison of specimens 1 and 3 indicates that an anodic coating on the aluminum surface decreased the load to a little less than one-half the load required for the unlubricated contact of bare steel to aluminum. A comparison of specimens 3 with 7 and 2 with 6 indicates that the use of a lubricant in addition to an anodic coating or in addition to cadmium plating was not beneficial.

It will be noted in table I that the four specimens in which the bushing was cadmium-plated (specimens 2, 4, 6, and 8) gave lower loads for press fits than even the lowest of the others. This reduction in load is attributed to the fact, borne out by observations during the press-fit operation, that at least a portion of the cadmium plating was removed from the bushing during the press fit, which reduced the initial interference between bushing and fitting. The actual reduction in interference caused by the removal of a portion of the cadmium plating is not known; but, as the original thickness of the cadmium plating is estimated to be approximately 0.0004 inch, the maximum change in interference was probably less than 0.0008 inch. Because of this probable change in interference, it is difficult to arrive at any definite conclusions concerning the effect of the cadmium plating. It can be stated, however, that for a given initial interference the cadmium plating reduces the load required for a press fit to less than one-third the load required for the unlubricated contact of bare steel and aluminum. A comparison of the results on specimens 2, 4, 6, and 8 indicates that the use of anodic coatings and lubrication in addition to cadmium plating does not decrease the pressure required for press fits beyond that for cadmium plating alone.

The microscopic examination made by the Metallurgical Division revealed no evidence of actual galling of the metal surfaces in any of the eight specimens submitted. A continuous layer of severely worked metal, which appeared to have been dragged along by the bushing, was found on the inside of the disk in the case of specimen 1. This condition suggests that, with slightly greater interference, galling probably would have been encountered and indicates that an unlubricated contact of bare steel and aluminum is undesirable in the press-fit operation. The microscopic examination also indicated that the anodically coated surfaces suffered considerably in the press-fit operation; but, from the pressures required for anodically coated samples, this treatment of the surface served a useful purpose in spite of this fact.

It was noted during the microscopic examination that some of the cadmium plating had been deposited on the aluminum-alloy surfaces on the inside of the aluminum-alloy disk. This deposit indicates that the cadmium plating was probably not entirely scraped off the steel bushing as it entered the hole in the disk and that the interference was, therefore, not altered quite as much as the 0.0008 inch mentioned as a possibile maximum in a previous paragraph.

Figure 3 shows photographs of the inside edges of three of the disks after the press fits were made. These photographs illustrate some of the conditions previously described.

The coefficients of friction for the various press-fit conditions were calculated from information in tables I and II and are given in table III. These values range from 0.33 for specimen 1 to 0.09 for specimen 2. The average coefficient of friction, excluding specimen 1 (unlubricated contact of bare steel and aluminum), is 0.12.

CONCLUSIONS

The following conclusions seem warranted as a result of the investigation described herein on eight different 17S-T aluminum-alloy fittings with pressed-in steel bushings:

1. An unlubricated contact of bare steel and aluminum should be avoided in making press fits of steel bushings and aluminum-alloy fittings because relatively high loads are required to make such press fits and more damage is done to the aluminum surface than if a lubricant is used.

2. Although no actual galling was encountered in any of the press fits in this investigation, the surface layer of the aluminum-alloy fitting, in the case of the press fit made with an unlubricated contact of bare steel and aluminum, was severely worked and appeared to have been dragged along by the bushing.

3. The use of Gredag No. 83 as a lubricant in making a press fit was found to be very beneficial when applied to otherwise bare steel and aluminum-alloy surfaces. The pressure required for such a lubricated press fit, adjusted for the difference in interference, was found to be only one-half as great as the pressure required for the unlubricated contact of bare steel and aluminum.

4. The use of anodic coating on the aluminum-alloy surfaces, even when unlubricated, decreased the pressure required for a press fit to less than one-half the pressure required for an unlubricated contact of bare steel and aluminum. The anodic coating itself was broken up and almost entirely removed by the press-fit operation, but the distortion of the surface layers of the aluminum was only slight compared with the distortion that occurred in the case of the unlubricated contact of bare steel and aluminum.

5. The use of cadmium plating on the steel bushing, even though unlubricated, decreased the pressure required for a press

fit to less than one-third the pressure required for unlubricated contact of bare steel and aluminum. A considerable portion of the cadmium plating was removed during the press fit, however, with the result that some of this reduction in load must be attributed to a decrease in effective interference.

6. Although lubrication with Gredag No. 83 proved highly beneficial when applied to otherwise bare steel and aluminum surfaces, the data in this investigation indicate no definite benefits for the cases in which lubrication was added in addition to the anodic coating or cadmium plating.

7. The calculated coefficients of friction for the various press fits for this investigation ranged from 0.33 for the unlubricated contact of bare steel and aluminum to 0.09 for the specimen with the unlubricated cadmium-plated bushing. The average coefficient of friction for all specimens, excluding the unlubricated contact of bare steel and aluminum, was found to be 0.12. Because these coefficients of friction are based entirely on calculated radial pressures and because the calculations are based on idealized conditions not strictly attained in these tests, they should be considered as being only approximately correct.

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REFERENCE

1. Timoshenko, S.: Strength of Materials. Pt. II. D. Van Nostrand Co., Inc., 1930, p. 533.

TABLE I

DATA FROM PRESS FITS OF STEEL BUSHINGS IN 17S-T FITTINGS

Specimen	Inside diam. of fittings (in.) (a)	Outside diam. of bushings (in.) (b)	Interference (in.)	Condition of 17S-T surface	Condition of steel surface	Lubricant	Max. load required to insert bushing into fitting (lb)	Adjusted load for an interference of 0.0028 in. (lb) (c)
1	0.8728	0.8756	0.0028	Bare	Bare	None	7160	7160
2	.8737	.8764	.0027	Bare	Cadmium-plated	None	1860	1950
3	.8733	.8756	.0023	Anodically coated[d]	Bare	None	2330	3000
4	.8743	.8764	.0021	Anodically coated[d]	Cadmium-plated	None	1600	2300
5	.8733	.8756	.0023	Bare	Bare	Gredag No. 83	2820	3600
6	.8737	.8764	.0027	Bare	Cadmium-plated	Gredag No. 83	2500	2600
7	.8733	.8757	.0024	Anodically coated[d]	Bare	Gredag No. 83	2560	3100
8	.8742	.8764	.0022	Anodically coated[d]	Cadmium-plated	Gredag No. 83	1790	2450

[a]Determined with Hoke precision gage blocks.

[b]Determined with Zeiss optimeter and Hoke precision gage blocks.

[c]See fig. 2.

[d]Chromic acid, AN-QQ-A-696.

TABLE II

COMPUTED PRESSURES AND STRESSES IN SPECIMENS OF

17S-T FITTINGS WITH PRESSED-IN STEEL BUSHINGS

[Values are only approximately correct because of limited applicability of formulas used]

Specimen	Interference (in.)	Radial pressure between fitting and bushing (lb/sq in.)	Max. stresses in bushing (lb/sq in.)		Max. stresses in fittings (lb/sq in.)	
			Circumferential compression	Shear	Circumferential tension	Shear
1	0.0028	10,600	43,300	21,600	19,200	19,900
2	.0027	10,200	41,600	20,800	18,500	19,100
3	.0023	8,700	35,500	17,800	15,800	16,300
4	.0021	7,900	32,300	16,200	14,400	14,900
5	.0023	8,700	35,500	17,800	15,800	16,300
6	.0027	10,200	41,600	20,800	18,500	19,100
7	.0024	9,100	36,700	18,500	16,500	17,000
8	.0022	8,300	33,900	16,900	15,100	15,600

TABLE III

CALCULATED COEFFICIENTS OF FRICTION FOR THE VARIOUS PRESS FITS

[Computed radial pressures are approximate]

Specimen	Interference (in.)	Computed radial pressure between fitting and bushing (lb/sq in.)	Max. pressure required for press fit (lb/sq in.) (a)	Computed coefficient of friction
1	0.0028	10,600	3480	0.33
2	.0027	10,200	900	.09
3	.0023	8,700	1130	.13
4	.0021	7,900	780	.10
5	.0023	8,700	1370	.16
6	.0027	10,200	1210	.12
7	.0024	9,100	1240	.14
8	.0022	8,300	870	.10

[a]These pressures were calculated by dividing the max. load required to insert bushing into fitting (from table I) by 2.06 sq in., which is the final area of contact between the steel bushing and the aluminum-alloy fitting.

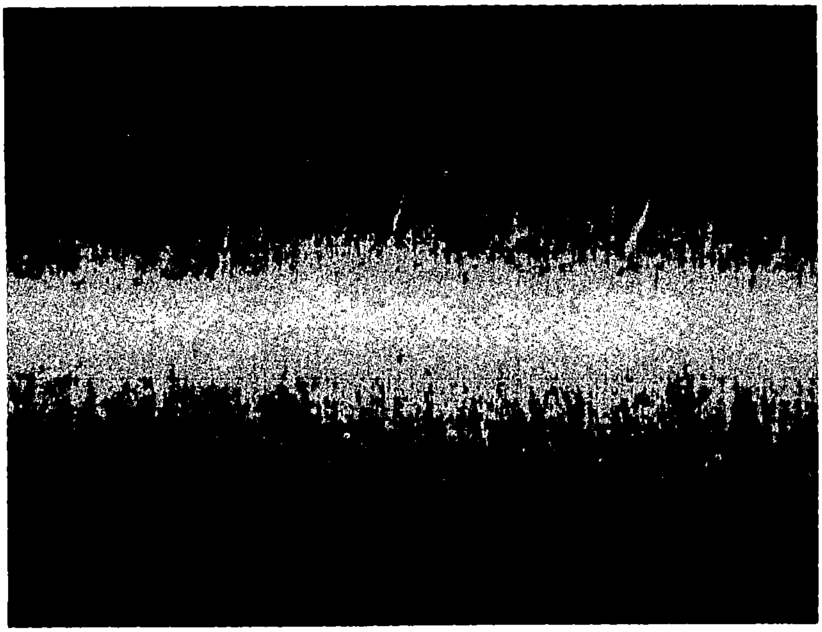


Figure 1.- Photograph showing finish on inside of hole bored in a 17S-T disk typical of the disks used in this investigation. 10X

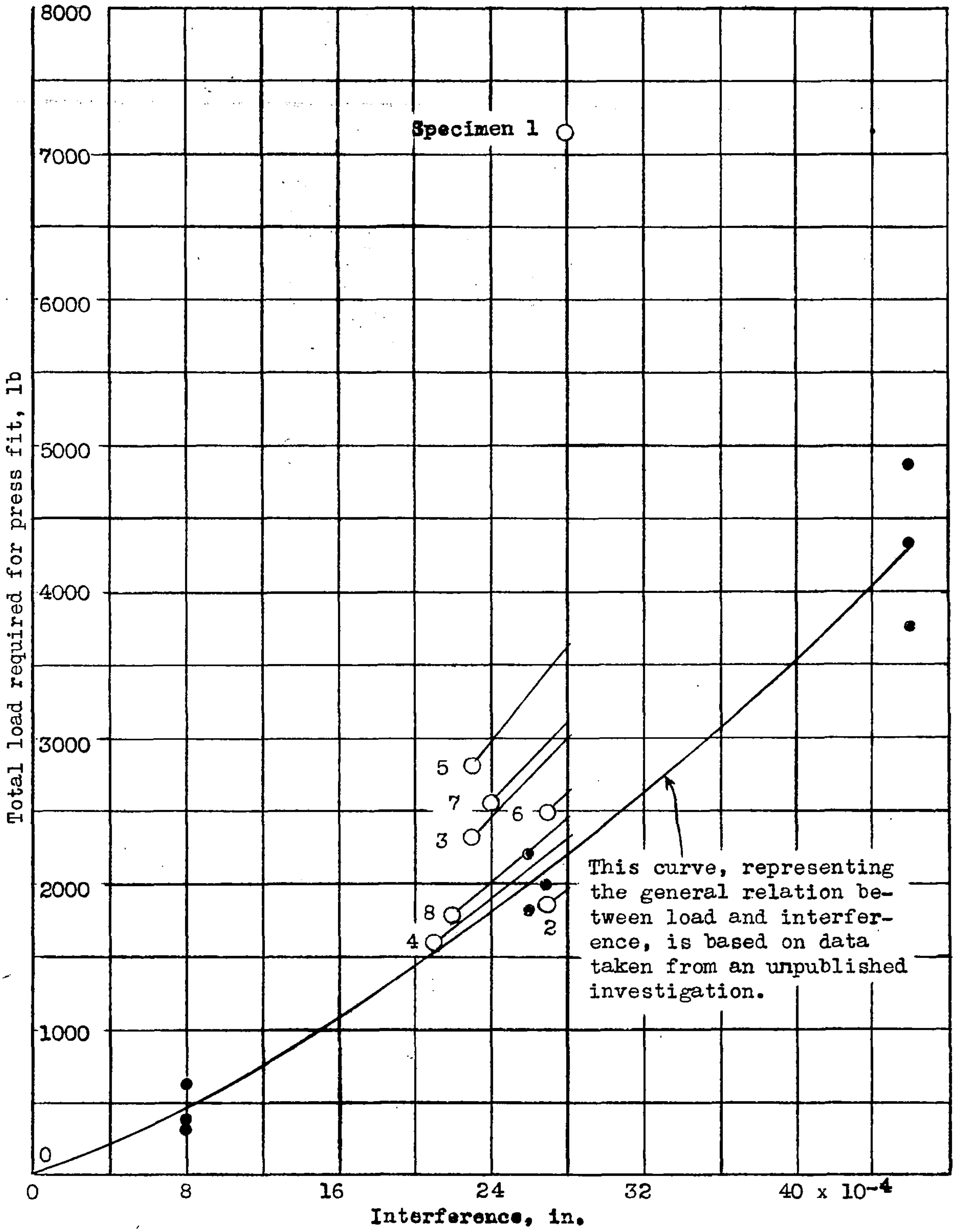
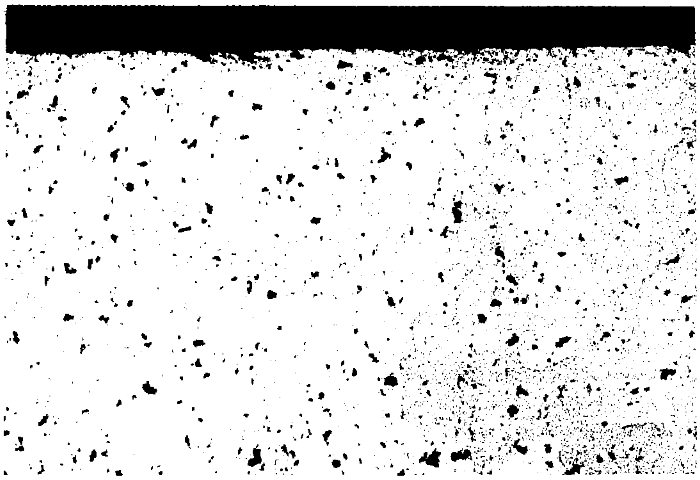
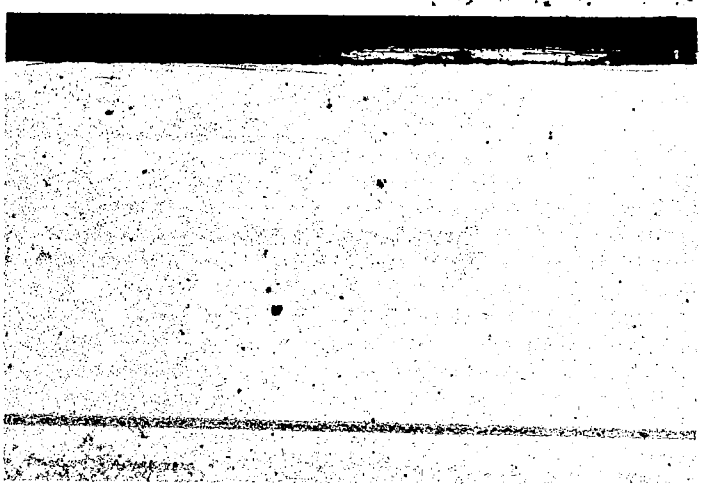


Figure 2.- Diagram for correcting loads to represent the same value of interference.

(a) Bushing, bare; without lubrication. Note severely worked surface layer, which appears to have been dragged along by the bushing. 500X



(b) Bushing, bare; lubricated with Gredag No. 83. 100X



(c) Bushing, cadmium-plated; without lubrication. Note cadmium picked up from bushing. 100X

Figure 3.- Longitudinal section through a bare 17S-T fitting in which steel bushing had been pressed.